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A new tram network for Bristol: a possible scenario?

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Some UK cities have seen the successful reintroduction of trams to complement and improve public transport services. This paper investigates the impact a hypothetical tramline would have in Bristol. This study was conducted in light of proposals for a bus rapid transit (BRT) network in Bristol. The literature review undertaken concludes that while BRT systems tend to have lower capital costs, a tram system could also be considered. At near-capacity operation, trams may be more effective in encouraging a modal shift away from travelling by car. Evidence from a preliminary simulation model, which was built to evaluate the demand a hypothetical tramline from the airport to the city centre would attract, suggests that a tram would encourage users to switch to public transport. Suggestions for further work for model refinement coupled with better understanding system impacts of the proposed tram system are included.

1. Introduction

The West of England's 'Joint Local Transport Plan' (JLTP) highlights the need for improved public transport in the Greater Bristol area. Much of this plan seeks to utilise bus rapid transit (BRT) corridors to increase connectivity in the city and reduce congestion (WEP, 2011). This paper explores the hypothetical development of a tram system. This paper analyses evidence reported in the literature and preliminary modelling evidence on the suitability of a tram system for Bristol. It reports some key findings from a research-design study conducted at the University of Bristol (Christopher *et al.*, 2014). The main objective of the modelling was to assess whether a hypothetical tram network could cause significant modal shifts (as highlighted in other case studies) and to estimate the number of users it could potentially shift from the car.

Bristol city lies in the southwest of England, 161 km from London. It is one of the UK's eight 'core cities', with a population of 432 500 inhabitants which is predicted to rise by a further 10.5% by 2021. Bristol has a comparatively young population with a median age of 33.7 years and low levels of unemployment. Although 29% of households in Bristol do not have cars, between 2001 and 2011 the number of cars on the road increased by 25 200 and the city is suffering from

increased congestion problems (aforementioned statistics and information from BCC, 2013).

This paper will not argue either for or against the currently planned BRT projects in Bristol, merely that a possible tram network is worthy of study. In the first part of this paper, reviews of some key regional transport plans are included and a comparison of BRT and trams is presented. The second part of the paper presents the results of some preliminary modelling of a hypothetical network for Bristol.

2. Background

The most recent tram line in the UK opened in Edinburgh in 2014 (<http://www.edinburghtrams.com/news/archive/2014/05>) albeit with controversy (e.g. Lowe, 2010). In 2012, 222 million journeys were completed on the UK's light-rail networks (DfT, 2013). The UK's largest network is the Manchester Metrolink, which opened in 1992 and has since been expanded (http://www.tfgm.com/Corporate/Media_Centre/Pages/facts_figures.aspx).

The purpose of the Metrolink was similar to the mandate set out in the JLTP – to improve access to the city centre by providing a congestion-free journey. The original route was successful and helped reduce traffic volume in the Bury–Manchester

corridor (as reviewed in Knowles, 1996). The network is currently undergoing further expansion, with a new line connecting Manchester Airport to the city and a second line being built across the city centre (http://www.tfgm.com/Corporate/Media_Centre/Pages/facts_figures.aspx). Although initial ridership was underestimated at first (Mackett and Edwards, 1998), the patronage of the Manchester Metrolink rose by 12% between 2012 and 2013 (DfT, 2013).

3. City public transport policy and plans

Bristol is primarily served by the Greater Bristol bus network, which has received a total capital investment of £79 million (Travel Plus, 2012). This outlay has focused on ten key routes in the Greater Bristol area to improve service frequency and reliability (WEP, 2011). New bus lanes have been introduced with priority signalling and bus stops have been upgraded to display real-time service information to improve the attractiveness of the service (WEP, 2011). Bristol also has a number of suburban rail lines, which operate at varied frequencies: the Severn Beach line has a less than hourly service to Bristol, whereas trains from Filton Abbey Wood run at 15 min intervals (Halcrow, 2012). At present, two major public transport projects are being considered for implementation. These are the Greater Bristol Metro rail improvements (hereafter referred to as MetroWest) and the Bristol Rapid Transit Bus Network (hereafter referred to as MetroBus) (TravelWest, 2014; WEP, 2011).

MetroWest will provide new railway stations in the West of England area and improve service frequency, with trains operating at a maximum interval of 30 min (WEP, 2011). Phase 1 involves (among other upgrades) the reopening of passenger services on the Ashton Gate to Portishead line and is due for completion in 2019 (see TravelWest, 2014). The project also involves four-tracking at Filton Bank to allow parallel running of local and national train services (WEP, 2011).

MetroBus is a BRT project connecting the south and north of Bristol through the city centre (scheme map available at <http://travelwest.info/wp-content/uploads/2015/03/metrobus-network-map.pdf>).

In addition to these two projects, BCC (2014) is introducing 20 miles/h (32 km/h) speed limits across Bristol with the stated aim of improving traffic flow and safety in the city centre.

4. Regional public transport policy and plans

The JLTP substantiates the need for investment in transport using the following key figures for the West of England; the annual cost of congestion will be £600 million by 2016; 253 people were killed or seriously injured in road accidents in 2009 and 19% of local CO₂ emissions come from local road transport (data from WEP, 2011). Furthermore, much of Bristol city

centre has been classified as an Air Quality Management Area by the Department for Environment, Food and Rural Affairs (DEFRA), the latest one being declared in 2008 (with respect to high levels of poisonous nitrogen dioxide) (http://uk-air.defra.gov.uk/aqma/details?aqma_id=757).

5. Prior Bristol tram networks and schemes

5.1 The Bristol Tramways and Carriage Company

Appleby (1969) gives a historical account of the original Bristol Tramways and Carriage Company's network. The following historical facts are taken from his book. According to Appleby, between 1875 and 1941, Bristol was served by an extensive open-top tram network. The first trams were horse drawn and in 1881 the network had 70 trams pulled by 300 horses (later rising to 85 trams and 500 horses). After the unsuccessful trial of steam power, the network was completely electrified by 1900. The trams operated with little interruption during the First World War, but by the 1920s they were seen as outdated and trolleybuses were predicted to be their successors. By 1939, 111 trams had been scrapped and replaced by buses. The Second World War delayed the complete decommission of the trams until bomb damage crippled the network in 1941 resulting in its closure.

5.2 Bristol Supertram

The idea of tramways in Bristol was revisited in the early 2000s with the proposal of the £200 million Bristol Supertram. The route was planned to connect Bristol's city centre with Bristol Parkway Station in order to help tackle congestion problems in the city (Symons, 2002). The Bristol Supertram formed part of the presiding government's 10-year plan to increase light-rail use across the UK (BCC, 2001). However, the project was not proceeded with.

6. BRT and trams

In their study, Hodgson *et al.* (2013) commented on the capital and operational expenditure of BRT systems to a light-rail network, they write

One way of generating ridership number for buses similar to light rail would be to make the bus look and feel like a tram...

Studying a theoretical network of the two systems in Reading in the UK, they concluded that the infrastructural costs of BRT were about two-thirds of those for a tram network, noting that BRT systems required high-quality infrastructure to match the comfort and operational performance of light rail (Hodgson *et al.*, 2013). Knowles (2007), after reviewing a National Audit Office Report (NAO, 2004), argues that costs of tram systems in the UK are disproportionately high because, among other reasons, there is a 'lack of standardisation' for their design; a 'slow planning and funding approval process' and 'inappropriate heavy rail safety standards' are

used. Regarding user perceptions, Mulley *et al.* (2014) argue that where cities have a positive experience of buses then a subsequent BRT is more likely to be successful.

While BRT systems may be cheaper to run per vehicle, tram operational costs are lower at high demand because BRT systems require greater staffing, operation and maintenance costs (Hodgson *et al.*, 2013). In their Reading modelling study, Hodgson *et al.* (2013) noted that 420 buses per week would need to operate to meet the required demand whereas a tram system would require only 260 vehicles. Hass-Klau and Crampton (2001) state that for some examples in Germany and the USA light rail is cheaper on a lifetime basis for comparable levels of service especially if running at near capacity.

Apart from the infrastructural costs, tram systems may be seen as more attractive than buses, which often carry a stigma as they may be seen as a 'second-class' mode of transport (CDOT, 2002 also reviewed in Currie, 2006). Hass-Klau and Crampton (2001) report data from 1986 to 1996 showing that European cities, which operated light-rail networks, seemed to attract more people to public transport than those that relied on buses. Although Hass-Klau and Crampton (2001) state that for light-rail transfer figures of more than 20% are the exception, the South Yorkshire Passenger Transport Executive (SYPT, 2009), responsible for the planning of Sheffield's transport network, revealed that 22% of passengers on the Supertram had previously been car users. In contrast to trams, buses had minor transfer rates, as low as <1–2.5% for some UK studies (Hass-Klau and Crampton, 2001). A review prepared for the Passenger Transport Executive Group by SDG (2005) concluded that in peak periods, if six trams ran per hour, 240 cars were removed from the road. In contrast, if 30 buses ran per hour, only 40 cars would be removed from the road.

Operational speeds of trams in cities also seem to fare better: in mixed traffic, buses have an average speed of 16.9 km/h, while trams have an average speed of 20.7 km/h (based on the average of survey data reported by Hass-Klau and Crampton, 2001).

The same study (Hass-Klau and Crampton, 2001) also noted that

Guided busways can be effective in overcoming bottlenecks when the road network is congested, but this could often be achieved more cheaply with strictly enforced bus lanes. In all cases, guided bus facilities and segregated busways seem to be unsuitable for city centres since they are too obtrusive and the feasibility for integration into a densely built-up urban environment is difficult or impossible.

In summary, while there are advantages to running a tram system, it is inconclusive whether they are always favoured over BRT. However, the review indicates that at least there is a *prima facie* case for re-examining the possibility of a new tram network for Bristol. A preliminary model of a hypothetical tram network for Bristol was prepared and some of the outcomes are presented in the next part of the paper.

7. Preliminary modelling

7.1 Proposed route

A city centre route and express link connecting Bristol International Airport to Bristol Temple Meads was used to model a tramline in Bristol. Figure 1 shows a schematic diagram of stop locations and integration with the existing railway network. It was assumed that bus routes would be adapted to operate in tandem with the tram network. More details on trial routes are given in Christopher *et al.* (2014).

7.2 Modelling standards and scope

The analysis was carried out in accordance with the Web-based Transport Analysis Guidance documents (WebTAG) (<https://www.gov.uk/transport-analysis-guidance-webtag>). PTV Visum software from PTV AG was used to model the traffic behaviour in the Bristol network (PTV AG, 2013). The purpose of the Bristol Trams model was to investigate the impact of a tram system on travel behaviour. The model analysed vehicle and people flows of a 'with tram' and 'without tram' scheme (DfT, 2014a).

To build the model, three datasets were developed, which contained network attributes, population data and travel behaviour. These were used for three sub-models: a network model, which contained information about the link capacities and speed limits; a four-step demand model, which generated trip frequencies between origin and destination (O–D) activity pairs; and an impact model which assigned the traffic to the model based on the cost impedances of the available trip paths (e.g. McNally, 2000; Ortúzar and Willumsen, 2001).

There was extensive information available to permit detailed modelling of the Bristol region. However, it was not feasible to complete a representative number of travel surveys and therefore, only government and census datasets were used for the model. This resulted in poor detail regarding the exact (O–D) trips.

7.3 Network model

Government guidelines state that the modelled area should be large enough to account for route choice impacts, but not overly large so that convergence and noise become an issue (DfT, 2014b). The model therefore has a fully modelled core, bounded by primary roads (Figure 2) and an external

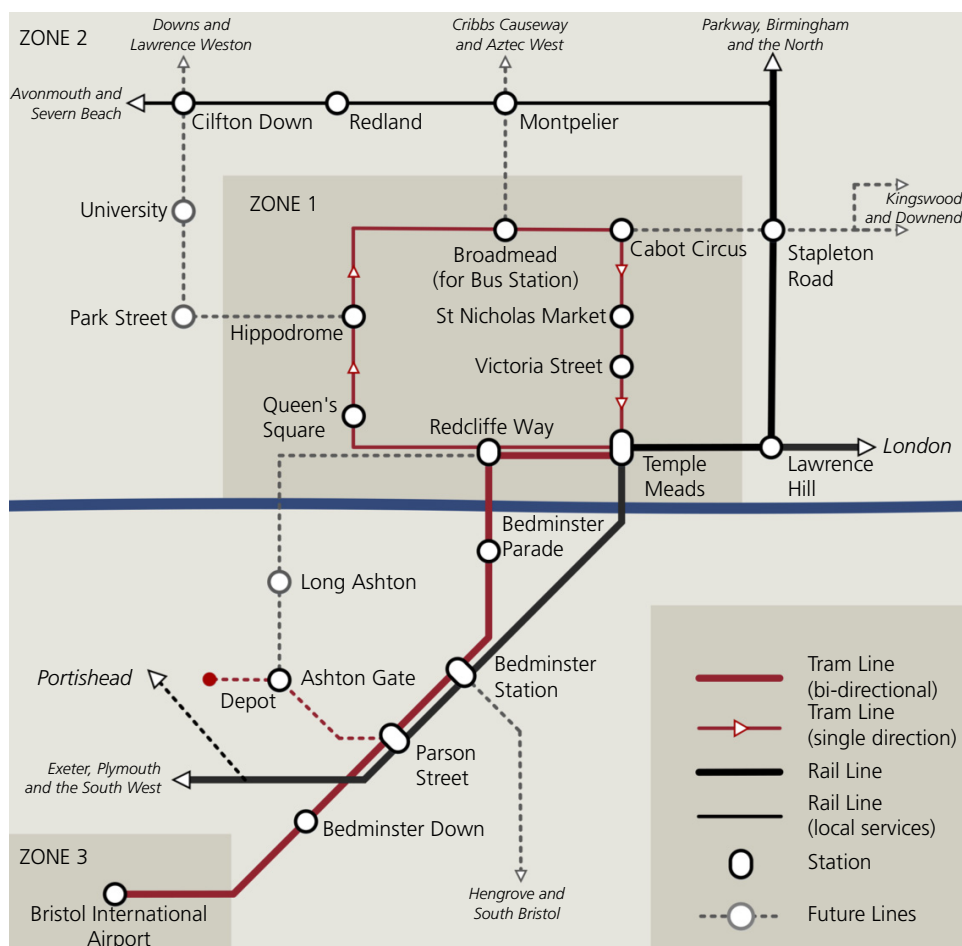


Figure 1. Schematic diagram of the hypothetical tram network

modelled area. The external area represents the remainder of Bristol, where it was assumed that the impact of the tram would be less apparent. These areas were modelled using a skeletal road network only. In line with guidelines, all road classes were included, although private roads, segregated cycle paths and footpaths were excluded due to licencing limitations (DfT, 2014c).

Network data were collected from data extracts of the Open Street Map (OSM). The Ordnance Survey Integrated Transport Network layer would have been preferential, but was incompatible with PTV Visum's importer. The model assumed that roads of the same class had the same capacity and speed attributes (Table 1). These generalised attributes were informed by the guidance given in WebTAG unit M3.1 (DfT, 2014c). In the model's external areas, the roads were assigned fixed speeds and link capacities were left unrestrained so that the travel costs to the fully modelled area were not responsive to the levels of demand (DfT, 2014c).

Public transport stop points were also imported from OSM. Public transport timetables from the Travel West website (<http://www.travelwest.info/>) were imported and simplified so that only the main pattern was observed. Bus and tram capacity were taken as around 70 and 230, respectively.

The 2011 LLSOA (lower level super output areas) census boundaries were used to represent the O-D zones. This boundary data resolution was chosen for two reasons: the specification was sufficient for the model and it was the most detailed layer compatible with the census workplace population dataset (<http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/super-output-areas--soas-/index.html>). The boundaries were extracted using Edina Digimap (<http://www.edina.ac.uk>). PTV Visum generated the centroid connectors, linking O-D zones to the network automatically. As few connectors as possible were used for external zones to help the model reach convergence more rapidly (DfT, 2014b).

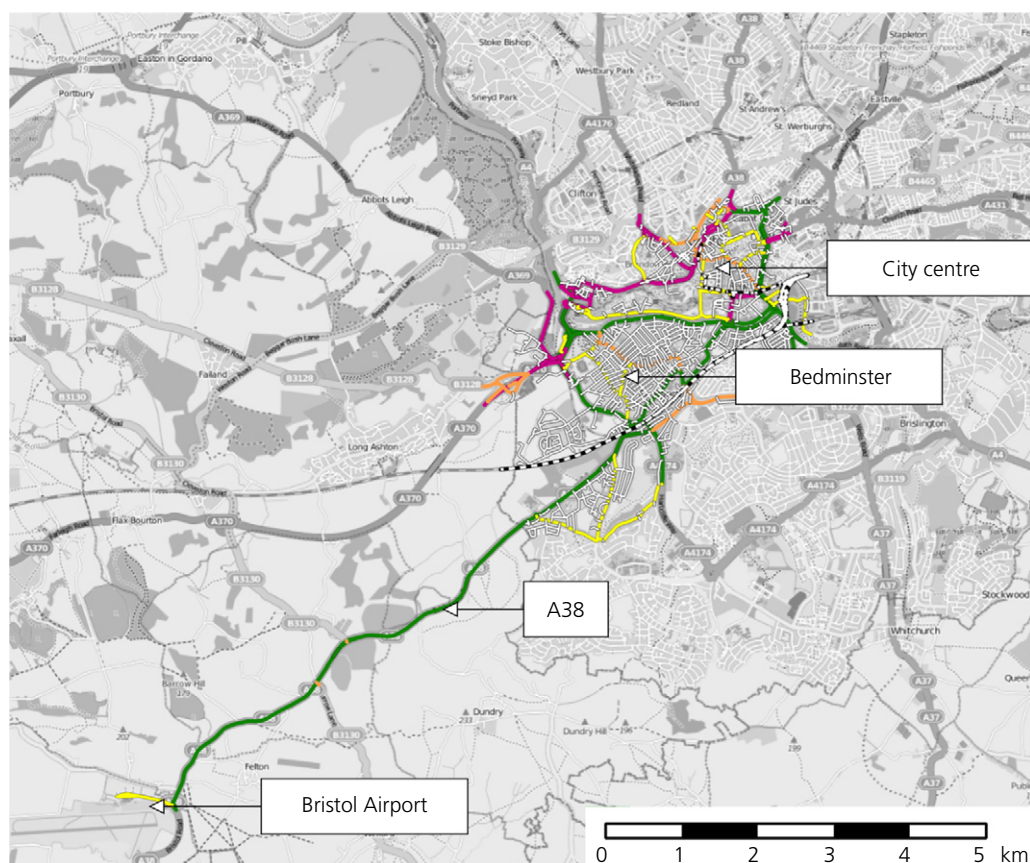


Figure 2. Modelled area (PTV Visum output)

7.4 Population data

Population data were extracted from the 2011 census datasets, based on Economic 'Activity' datasets and the 'Workplace' dataset to generate demand and O-D pairs. At the time of the study, 2011 flow data had not been published and therefore flow data could not be considered. The 'Car and Van Ownership' dataset was used to calculate the proportion of car users (<http://www.nomisweb.co.uk/>). Additionally, education places from the government's EduBase website were used to model student travel. Population growth estimates were extracted from the National Trip End model using TEMPro (available from <http://www.gov.uk/government/collections/tempo>).

To model trips at Bristol Temple Meads station and Bristol International Airport, artificial zones were created with populations based on their usage statistics. These data were obtained from CAA (2013) and ORR (2013).

7.5 Travel behaviour

Travel behaviour inputs for the model were interpreted using datasets from the 2012 National Travel Survey; this included

trips in progress by time of day, the modal share, travel purpose and occupancy rates (datasets from <https://www.gov.uk/government/collections/national-travel-survey-statistics>). In line with WebTAG recommendations, a variety of activity pairs were initially built for the model. These included home-based and non-home-based activity pairs (DfT, 2014b). Insufficient data were available in the correct format to allow activity pairs to be modelled. Instead, one generalised activity pair was generated, which modelled trips from the home to the workplace.

Furthermore, WebTAG guidelines recommend that activity pairs should be assigned to activity classes, which reflect travel behaviour based on the perceptions of cost. The most basic models should have the following activity classes to reflect the traveller's perception of cost: employer's business, commuting and other (DfT, 2014b). Sufficient data were available to design these classes; however, because there was only one activity pair, only one trip category could be used. The perceptions of cost were taken from the average values made available in the WebTAG data booklet (<https://www.gov.uk/government/>

Road classes	Description	Speed limit: miles/h (km/h)	Capacity: vehicle/h/dir
1	Rural single carriageway	60 (100)	900
2	Rural all-purpose dual two-lane carriageway	70 (112)	1600 ^a
7	Urban non-central	30 (48)	800 ^a
8	Urban central	30 (48)	800 ^a
10	Suburban single carriageway	40 (64)	1350
11	Suburban dual carriageway	40 (64)	1350 ^a

^avehicle/h/lane

Table 1. Road classes and capacities (DfT, 2014c)

uploads/system/uploads/attachment_data/file/313141/tag-data-book-autumn-2013.xls).

7.6 Model processes

Figure 3 shows the modelling methodology used to investigate the impact of a tramline in Bristol. The model was built to represent current travel patterns and validated before growth forecasts were applied. The 2030 base model was used as the ‘without tram’ scheme as comparison for the ‘with tram’ scheme. The model calculation sequence (Figure 4) was based on an example set out by PTV.

7.7 Network calibration

To ensure accuracy of the network, the model was calibrated by inspection. Further calibration was not possible due to the lack of local travel survey information available. Time constraints of the project meant that not all of the 1900 nodes in the network could be checked. Therefore, only main roads and the tram route links were checked and calibrated against any relevant Highways Agency Traffic Information System information that was available for download (<https://www.hatris.co.uk>). The bus route to the airport was calibrated using ridership data supplied in Bristol International Airport’s annual report (BA, 2012).

7.8 Network validation

The Department for Transport’s 2012 traffic counts was used to validate the model (<http://www.dft.gov.uk/traffic-counts>). Figure 5 highlights the traffic locations. WebTAG guidelines stipulate that the absolute and percentage differences between the modelled and actual flow should be used to validate the model. Additionally, the GEH formula should also be used to validate the network. The GEH formula (Equation 1) is based on the Chi-squared statistic and contains both relative and absolute error. Its inputs are modelled (M) and observed (C) flow (veh/h) (DfT, 2014c)

$$1. \quad GEH = \sqrt{\frac{(M - C)^2}{(M + C)/2}}$$

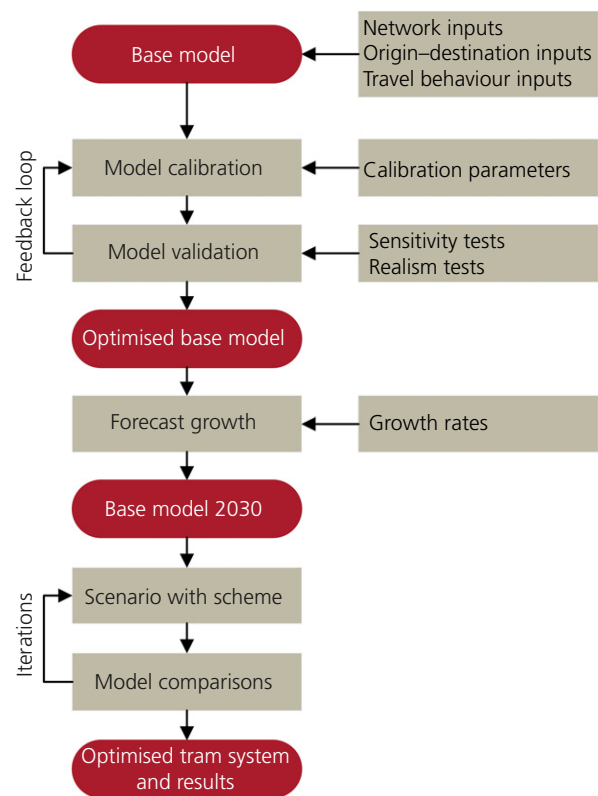


Figure 3. Model processes (based on Ortúzar and Willumsen, 2001; TfL, 2010)

Usually, a model is assumed valid if, in 85% of all cases, link flows are within 15% of the measured flow (exact criteria are dependent on link size). The GEH statistic value should be <5. This condition is met around half the time (Table 2), which was considered acceptable for the preliminary modelling stage. Table 2 shows the result of the validation testing. The modelled public transport flows were closer to the tolerance levels, possibly because there was more information contained within the model such as the bus schedules.

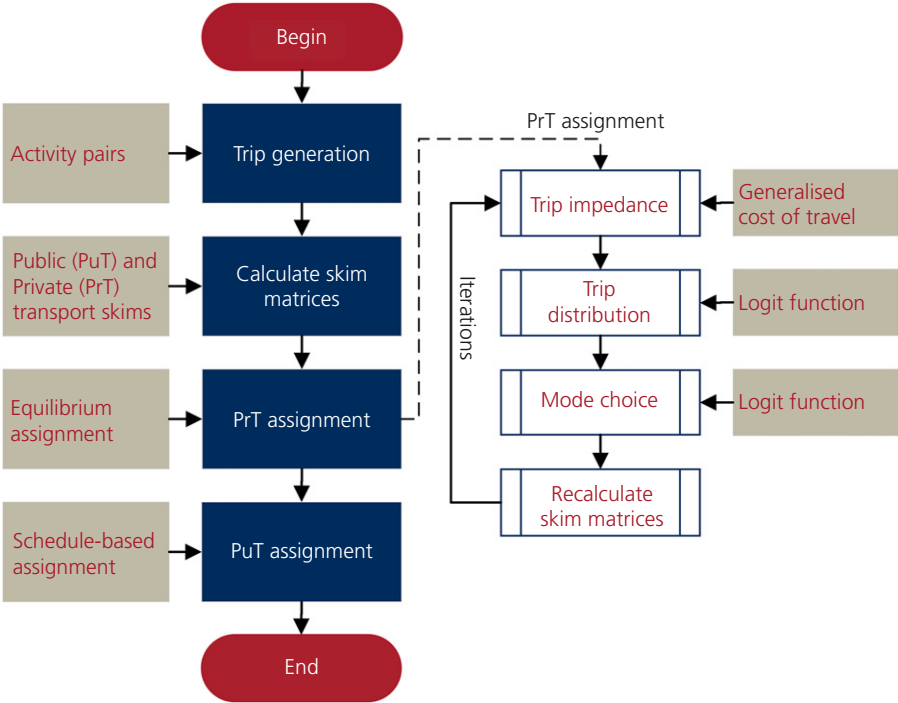


Figure 4. Model calculations (based on data from PTV AG, 2013)



Figure 5. Count locations (PTV Visum output)

Measured road	Traffic count identifier	Measured AADF ^a		Modelled AADF		GEH	
		Car: veh	PSV ^b : veh	Car: veh	PSV: veh	Car	PSV
A38	6401	7696	462	10 803	576	32.3	5
A4018	7617	20 392	756	22 585	765	15	0.3
A38	8390	16 352	329	22 503	528	44.1	9.6
A38	26 404	12 768	813	19 068	1210	49.9	12.5
A38	36 410	12 308	294	12 923	358	5.5	3.5
A38	38 142	17 343	306	26 356	264	61	2.5
A4044	46 408	6731	683	6122	979	7.6	10.3
A4	48 459	36 022	1615	37 316	1914	6.8	7.1
A4044	56 375	24 562	745	28 332	779	23.2	1.2
A4044	56 376	24 562	745	23 559	713	6.5	1.2
A4044	56 400	36 918	1456	32 789	1229	22.1	6.2
A38	58 068	18 037	222	18 507	288	3.5	4.1
A38	73 303	9676	353	12 246	355	24.5	0.1
A38	74 625	15 158	159	19 194	288	30.8	8.6
A38	74 770	21 281	321	21 681	800	2.7	20.2
A38	74 772	21 281	321	9499	825	95	21.1

^aAnnual average daily flow

^bPublic service vehicle

Table 2. Sample of validation results

7.9 Realism and sensitivity testing

Fuel prices were increased by 20% and the accumulated car vehicle kilometres analysed to determine the elasticity of fuel prices. WebTAG guidelines suggest that the average fuel elasticity should be between -0.25 and -0.35 (DfT, 2014b). The Bristol Trams model had a response change of -0.61 . The main limitation controlling the response to costs was the traveller's assigned value of time. The Bristol Trams model contained only one user class and therefore the response to travel impedances was limited.

7.10 Model assumptions and limitations

The modelling process was limited by the amount of data available and by the allowable network size. Restricted processing power also meant that iterations were limited to a maximum of five. Similarly, the incremental assignment was restricted to three steps in order to increase the speed of calculations.

Assignment was assumed to be link-based only. There was insufficient available data to allow the junctions to be modelled and therefore the junction capacities were set as unrestricted to remove them as a variable. Furthermore, due to licensing constraints, the model only considered the following modes of transport, the petrol car, bus, tram and walking. Heavy goods vehicle trips were not included in the model, since this mode was considered not to be directly relevant to the demand of

the tram. The modal share of bicycle travel has also been excluded due to licensing limitations and it has been assumed that tram ridership is unrelated to trips made by bicycle.

It was assumed that the modelled area contains all origins and destinations. The model failed to account for O-D pairs that start or end outside the modelled zones; hence, their effect on traffic flow is neglected. The model also assumed the worst-case scenario of weekday travel.

Due to the lack of sufficient survey data, only one general user class was modelled and it was assumed that all users, regardless of whether their travel purpose or demographic, had the same perception of cost.

8. Discussion

The model's results were based on travel behaviour to the airport as these gave the clearest results regarding the tram's impact. The model suggested that a tram system in Bristol is viable and Figure 6 highlights the potential passenger volumes. Approximately 18 300 people per day would travel on the new Airport Express line. This scenario, when compared with the existing transport network, encourages a modal shift of nearly 1200 riders. The line also attracts up to 7000 more users in Bedminster. In the tramline's catchment area, car usage is reduced by as many as 1000 cars per day on some parts of the

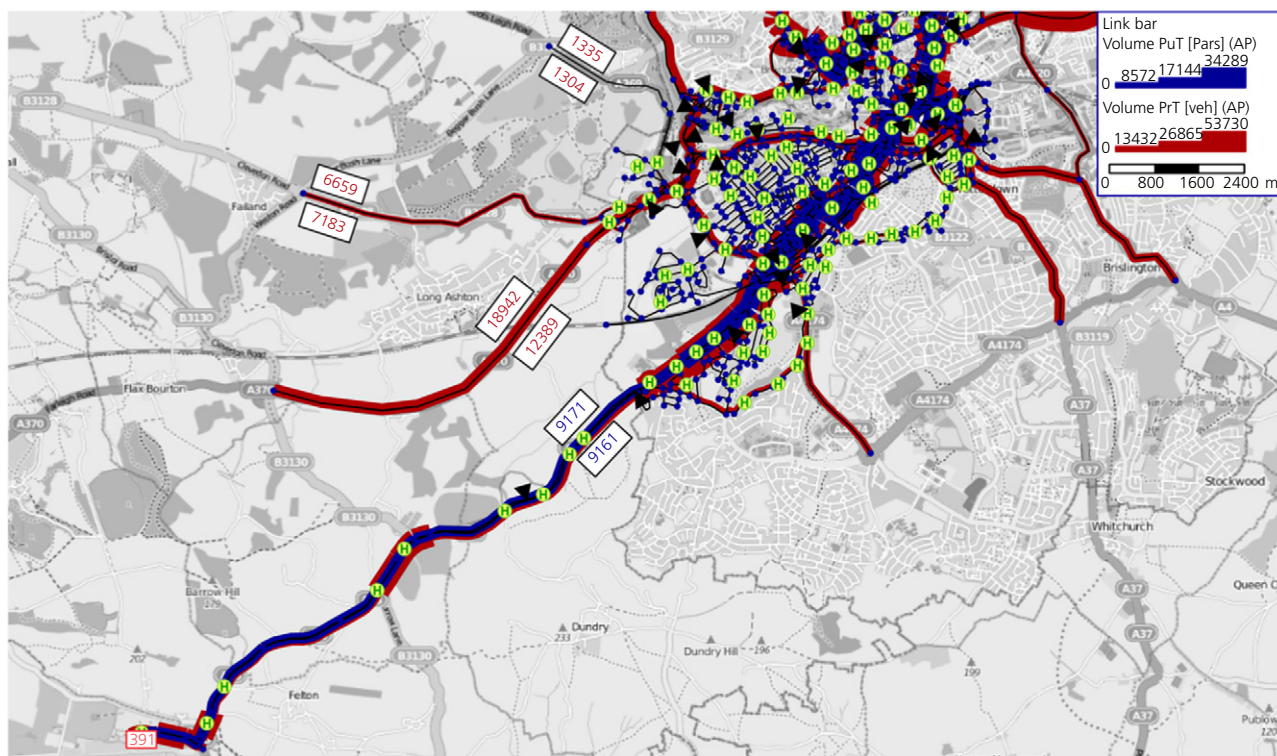


Figure 6. Model output: demand of a tramline in 2030 (PTV Visum output)

A38 in Bedminster, which is likely to have a positive impact on congestion problems.

A major factor of the user's perceived cost was the trip time. Figure 7 shows the estimated time saved by users travelling from the airport to the city centre by tram compared with the existing bus network. As the tram was modelled to run at 100 km/h adjacent to the A38 between the airport and the city edge without stopping, users were able to enjoy a 10 min journey time saving. This time gain was eroded a little in the city due to waiting times to connecting services. Existing stops along the A38 were modelled as not being served by the tram.

Future work will need to study issues of market share in terms of trips to and from the airport and within the city today. Bottleneck points in the transport network will also have to be identified to help inform how alignments could be improved. The use of dynamic simulation models such as OpenTrack (<http://www.opentrack.ch>) may give better indications of run-times and rolling stock requirements. These inputs could be used to develop preliminary service and operations concepts that could be fed back into the model to better understand system performance and costs. In addition, the societal benefits should also be studied such as the potential social revenues

gleaned from cost, reduced congestion and decreased pollution rates.

9. Summary remarks

- Current transport plans for the Bristol region already focus heavily on public transport investment. From the review, it is apparent that there is both the need and political motivation to provide finance for major public transport schemes. The importance of public consultation should not be neglected (e.g. Ng *et al.*, 2012, 2014).
- Collected data from the literature suggest that although BRT systems tend to have lower capital costs, trams have potentially lower operational costs; may be more successful in effecting a modal shift away from the car. Therefore, their revival in Bristol may be worth considering.
- The results of the preliminary modelling suggest positive modal shifts with the introduction of a tram network, but further work could be done to refine the model. A greater portion of Bristol could be modelled to gain a better understanding of where people are travelling to and which transport modes they would use. O-D information could be collected using the ONS flow data and

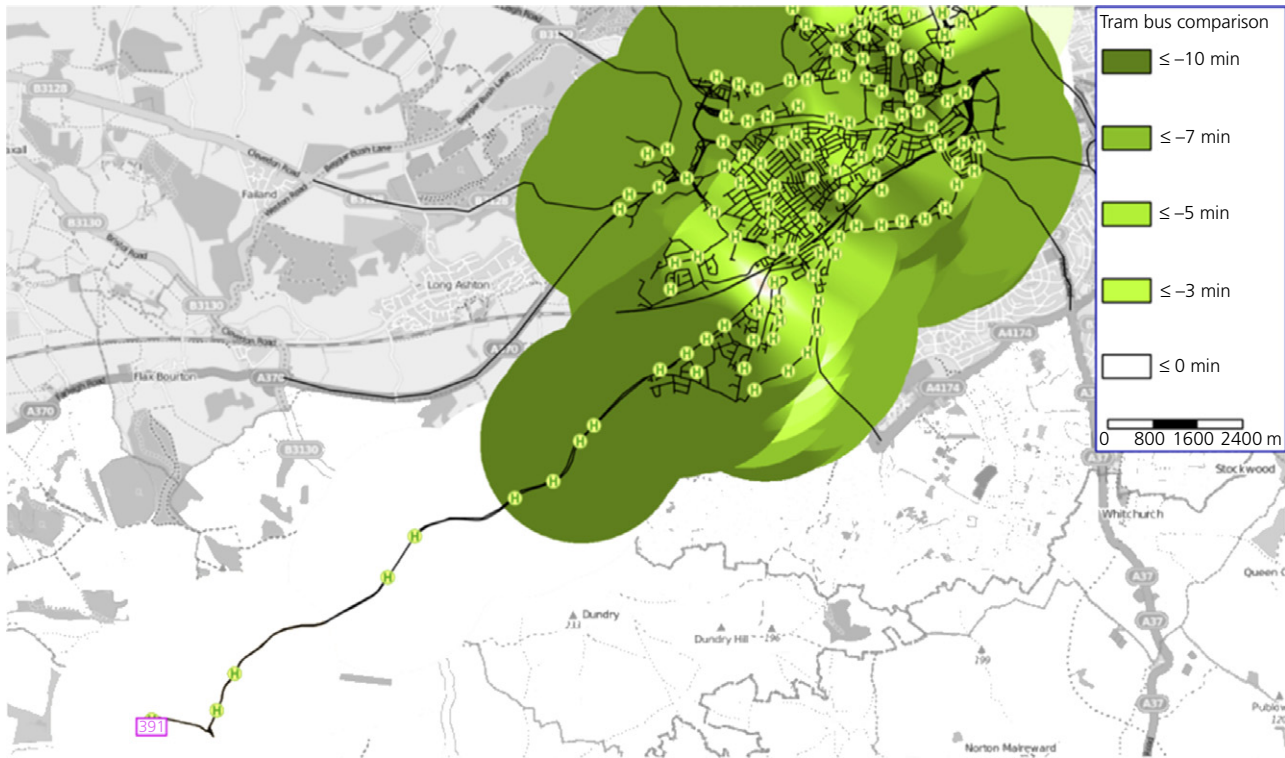


Figure 7. Model output: time saved using the tram against the existing bus network (PTV Visum output)

by conducting roadside surveys. Users' perceptions of cost could also be improved by including inputs such as value of time according to trip purpose, income band and age. Furthermore, an improved model could include competing transport modes in greater detail, for example a concurrent BRT system.

- Further junction modelling should also be carried out, with greater detail being applied to major junctions. The model should investigate a number of different scenarios including rush hour, weekends and school holiday periods, in order to investigate the overall demand for tram services.

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REFERENCES

- Appleby JB (1969) *Bristol's Trams Remembered*. J.B. Appleby, Westbury-on-Trym, Bristol, UK.
- BA (Bristol Airport) (2012) *2012 Operations Monitoring Report*. The Planning & Environmental Department, Bristol
- Airport, Bristol, UK, 25pp. <http://www.bristolairport.co.uk/~media/files/brs-airport/content/operations-monitoring-reports/2012-Operations-Monitoring-Report.ashx> (accessed 21/04/2015).
- BCC (Bristol City Council) (2001) *Bristol Local Transport Plan – Annual Progress Report 2001*. BCC, Bristol, UK, 72pp. <http://www.bristol.gov.uk/sites/default/files/assets/documents/ptsd-Annual-Progress-Report-2001.pdf> (accessed 21/04/2015).
- BCC (2013) *State of the City 2013*. BCC, Bristol, UK. http://www.bristol.gov.uk/sites/default/files/documents/council_and_democracy/statistics_and_census_information/State%20of%20the%20City%202013-%20Mayoral%20vision%20v8.pdf (accessed 21/04/2015).
- BCC (2014) *A Little Bit Slower. A Whole Lot Better – Information Pack for Businesses and Organisations*. BCC, Bristol, UK. <http://www.bristol20mph.co.uk/sites/default/files/documents/20mph%20Business%20Information%20Pack.pdf> (accessed 21/04/2015).
- CAA (Civil Aviation Authority) (2013) *Terminal and Transit Passengers 2013*. CAA. https://www.caa.co.uk/docs/80/airport_data/2013Annual/Table_09_Terminal_and_Transit_Pax_2013.pdf (accessed 21/04/2015).

- CDOT (California Department of Transportation) (2002) *Statewide Transit-Orientated Development Study – Factors for Success in California*. Business, Transportation and Housing Agency, 217pp, Final Report. <http://www.dot.ca.gov/hq/MassTrans/Docs-Pdfs/TOD-Study-Final-Rpt.pdf> (accessed 21/04/2015).
- Christopher P, Kennedy C, Pollock Fraser H and Webster T (2014) *Bristol Trams 2030*. University of Bristol, Bristol, UK, 70pp, Design Project IV (Project M2014/27) – MEng Project Report.
- Currie G (2006) Bus transit oriented development-strengths and challenges relative to rail. *Journal of Public Transportation* **9(4)**: 1–22.
- DfT (Department for Transport) (2013) *Light Rail and Tram Statistics: England 2012/13*. DfT, London, UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/207006/light-rail-and-tram-statistics-2012-13.pdf (accessed 21/04/2015).
- DfT (2014a) *Tag Unit M1 Principles of Modelling and Forecasting*. DfT, London, UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/373138/webtag-tag-unit-m1-1-principles-of-modelling-and-forecasting.pdf (accessed 21/04/2015).
- DfT (2014b) *Tag Unit M2 Variable Demand Modelling*. DfT, London, UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/373137/webtag-tag-unit-m2-variable-demand-modelling.pdf (accessed 21/04/2015).
- DfT (2014c) *Tag Unit M3.1 Highway Assignment Modelling*. DfT, London, UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/370621/webtag-tag-unit-m3-1-highway-assignment-modelling.pdf (accessed 21/04/2015).
- Halcrow (2012) *West of England Area Rail Studies*. Halcrow, Birmingham, UK. <http://travelwest.info/wp-content/uploads/2015/03/west-of-england-rail-studies-report-april-2014.pdf> (accessed 21/04/2015).
- Hass-Klau C and Crampton G (2001) Buss or light rail – which is best? In *Any More Fares?: Delivering Better Bus Services* (Grayling T (ed.)). IPPR, London, UK, pp. 92–108.
- Hodgson P, Potter S, Warren J and Gillingwater D (2013) Can bus really be the new tram? *Research in Transport Economics* **39(1)**: 158–166.
- Knowles RD (1996) Transport impacts of greater Manchester's Metrolink light rail system. *Journal of Transport Geography* **4(1)**: 1–14.
- Knowles RD (2007) What future for light rail in the UK after ten year transport plan targets are scrapped? *Transport Policy* **14(1)**: 81–93.
- Lowe JG (2010) Edinburgh trams: a case study of a complex project. In *Proceedings 26th Annual ARCOM Conference, 6–8 September 2010* (Egbu C (ed.)). Association of Researchers in Construction Management, Leeds, UK, pp. 1289–1298, http://www.arcom.ac.uk/-docs/proceedings/ar2010-1289-1298_Lowe.pdf (accessed 21/04/2015).
- Mackett RL and Edwards M (1998) The impact of new urban public transport systems: will the expectations be met? *Transportation Research Part A: Policy and Practice* **32(4)**: 231–245.
- McNally MG (2000) *The Four Step Model*. University of California, Irvine, CA, USA, 18pp, Report No. UCI-ITS-AS-WP-00-5. <http://www.its.uci.edu/its/publications/papers/CASA/UCI-ITS-AS-WP-00-5.pdf> (accessed 21/04/2015).
- Mulley C, Hensher DA and Rose J (2014) Do preferences for BRT and LRT vary across geographical jurisdictions? A comparative assessment of six Australian capital cities. *Case Studies in Transport Policy* **2(1)**: 1–9.
- NAO (National Audit Office) (2004) *Improving Public Transport in England Through Light Rail, Report by the Comptroller and Auditor General HC518 Session 2003–2004*. The Stationery Office, London, UK, 47pp. <http://www.nao.org.uk/wp-content/uploads/2004/04/0304518.pdf> (accessed 21/04/2015).
- Ng ST, Li THY and Wong JMW (2012) Rethinking public participation in infrastructure projects. *Proceedings of the Institution of Civil Engineers – Municipal Engineer* **165(2)**: 101–113, <http://dx.doi.org/10.1680/muen.11.00027>.
- Ng ST, Skitmore M, Tam KY and Li THY (2014) Public engagement in major projects: the Hong Kong experience. *Proceedings of the Institution of Civil Engineers – Municipal Engineer* **167(1)**: 22–31, <http://dx.doi.org/10.1680/muen.13.00009>.
- ORR (Office of Rail Regulation) (2013) *Station Usage Estimates 2012–13*. ORR. http://orr.gov.uk/_data/assets/excel_doc/0003/10785/Station-Usage-2012-13_Final.xls.xls (accessed 21/04/2015) (MS Excel spreadsheet).
- Ortúzar JD and Willumsen LG (2001) *Modelling Transport*, 3rd edn., Wiley, London, UK.
- PTVAG (2013) *PTV Visum Fundamentals*. PTVAG, Karlsruhe, Germany.
- SDG (Steer Davies Gleave) (2005) *What Light Rail Can Do for Cities: A Review of the Evidence*. SDG, London, UK. http://www.pteg.net/system/files/general-docs/WhatLightRailCanDoforCitiesMainText_0218.pdf (accessed 21/04/2015).
- Symons J (2002) Bristol Supertram: can it be rescued? *Tramways and Urban Transit*, July 2002: p. 273.
- SYLTE (South Yorkshire Passenger Transport Executive) (2009) *Tram Strategy and Delivery Plan*. SYLTE. http://www.sypte.co.uk/uploadedFiles/Corporate/Plans_and_Strategies/Tram%20Strategy.pdf (accessed 21/04/2015).
- TfL (Transport for London) (2010) *Traffic Modelling Guidelines: TfL Traffic Manager and Network Performance Best Practice Version 3.0* (Smith J and Blewitt P (eds)). TfL,

London, UK. <http://www.tfl.gov.uk/cdn/static/cms/documents/traffic-modelling-guidelines.pdf> (accessed 21/04/2015).

Travel Plus (2012) *The Greater Bristol Bus Network*. Travel Plus, London, UK. http://www.bristol.gov.uk/sites/default/files/documents/transport_and_streets/roads_safety/buses/GBBN%20brochure%20-%20March%202012.pdf (accessed 21/04/2015).

TravelWest (2014) *MetroWest: Investing in Our Local Rail Network*. TravelWest. <http://travelwest.info/wp-content/uploads/2015/03/metrowest-an-overview.pdf> (accessed 21/04/2015).

WEP (West of England Partnership) (2011) *West of England Joint Local Transport Plan 3 2011 – 2026*. WEP. <http://travelwest.info/wp-content/uploads/2015/03/joint-local-transport-plan.pdf> (accessed 21/04/2015).

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